QoE-aware Multiple Path Video Transmission for Wireless Multimedia Sensor Networks

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Abstract. *Wireless Multimedia Sensor Networks (WMSNs) promise a wide scope of emerging potential applications in both civilian and military areas, which require visual and audio information to enhance the level of collected information. The transmission of multimedia content requires a minimal video quality level from the user's perspective. However, links in WMSN communications are typically unreliable, as they often experience fluctuations in quality and weak connectivity, and thus, the routing protocol must evaluate the routes by using end-to-end link quality information to increase the packet delivery ratio. Moreover, the use multiple paths together with key video metrics can enhance the video quality level. In this paper, we propose a video-aware multiple path hierarchical routing protocol for efficient multimedia transmission over WMSN, called video-aware MMtransmission. This protocol finds node-disjoint multiple paths, and implements an end-to-end link quality estimation with minimal overhead to score the paths. Thus, our protocol assures multimedia transmission with Quality of Experience (QoE) and energy-efficiency support. The simulation results show the benefits of video-aware MMtransmission for disseminating video content by means of energy-efficiency and QoE analysis.*

1. Introduction

The proliferation of multimedia content and the demand for new audio/video services in Internet of Things (IoT) applications [Zhou and Chao 2011] have fostered the development of a new era based on multimedia information. Those applications allowed the evolution of Wireless Multimedia Sensor Networks (WMSNs) [Almalkawi et al. 2010], which enable a large class of scenarios ranging across diverse areas, e.g., environmental monitoring, video surveillance, traffic control, smart cities, and other IoT applications. The multimedia content in such applications gives support to the end-users (or systems) to visually verify the real impact of events, and be aware of what is happening in the environment with rich visual information.

Multimedia delivery demands high bandwidth, real-time transmission, lower frame loss, tolerable end-to-end delay and jitter. Additionally, applications involving multimedia dissemination should support Quality of Service (QoS) and Quality of Experience

(QoE) to deliver video content with, at least, a minimal video quality level from the user's perspective together with energy-efficiency and scalability [Jaime et al. 2010]. Those issues impose more constraints on the design of a routing protocol for WMSNs. Further, frames with different priorities compose a compressed video, and from a human's experience, the loss of high priority frames causes severe video distortion. Thus, a key principle in a QoE-aware routing protocol for WMSNs in IoT applications is the transmission of high priority frames (protect) with minimum packet loss [Greengrass et al. 2009].

Nevertheless, low-power radios employed by WMSNs are very sensitive to noise, interference, and multipath distortion, which cause link unreliability. These issues also impose serious effects on wireless communication quality, due to significant link quality fluctuations and weak connectivity [Baccour et al. 2011]. In this context, link quality estimation is an essential metric to enable the nodes to dynamically plan, adapt and take appropriate actions when making a routing decision. However, a reliable mechanism to support route selection based on both cross-layer information and end-to-end link quality estimation with minimum overhead is still needed [Gomez et al. 2010].

Multi-path routing aims to provide load balance, bandwidth aggregation and reduced delay, compared to single-path transmission [Radi et al. 2012]. Though, the multiple paths must be node-disjoint to avoid a common node among different paths. Node-disjoint multi-path routing mitigates packet losses at relay nodes with restricted buffer, and thus, enhances the packet delivery ratio. Additionally, WMSN route selection should consider both cross-layer information and end-to-end link quality estimation to find node-disjoint multi-path routes. Moreover, priority frames must be protected in congestion/link error periods. However, current WMSN routing protocols do not consider all of these key characteristics to support QoE-aware multimedia transmission.

This paper proposes a video-aware multiple path hierarchical routing protocol for efficient multimedia transmission over WMSN, called *video-aware MMtransmission*. The proposed protocol assures multimedia transmission with both QoE and energy-efficiency support. In specific terms, video-aware MMtransmission finds reliable node-disjoint multiple paths, and evaluates in an end-to-end fashion by using cross-layer information. The route discovery includes a minimum signaling overhead, as expected for many IoT applications. Moreover, the protocol uses key video information to disseminate high priority video frames via more reliable paths with the aims of increase the video quality level.

We performed simulations to evaluate the energy-efficiency and video quality level of video-aware MMtransmission. We analyzed the video quality by means of two well-known QoE objective metrics, namely *Structural Similarity (SSIM) and Video Quality Metric (VQM)*. The results showed that the proposed protocol provides multimedia distribution with a higher quality level compared to other approaches. Our protocol has a SSIM gain of approximately 10% and a VQM gain of 10% to 40%.

The remainder of the paper is structured as follows. Section 2 outlines existing routing protocols for WMSNs. Section 3 describes the video-aware MMtransmission protocol for WMSNs, which was evaluated by means of simulation experiments as presented in Section 4. Section 5 presents main contributions and results of this paper.

2. Related Work

Several attempts have been made to achieve promising results in routing protocols for WMSN applications, and in general such works focus on minimizing energy consumption and meeting certain QoS requirements for multimedia distribution. Further, they establish a hierarchical architecture to achieve lower energy consumption, higher functionality, better scalability and greater reliability [Ehsan and Hamdaoui 2011].

[Kandris et al. 2011] proposed Power Efficient Multimedia Routing (PEMuR) based on a combination of hierarchical routing and video packet scheduling models to support efficient video communication in WMSNs. PEMuR considers only the remaining energy to find routes (not link quality), and this issue limits the transmission of multimedia content with QoS/QoE support due to unreliability of the low-power wireless links. As PEMuR also relies on a centralized scheme to create clusters, it does not consider multiple paths to balance load, aggregate bandwidth, and reduce delay. [Politis et al. 2008] introduce a multi-path routing over a hierarchical architecture, and employs two packet scheduling algorithms to transmit video packets over multiple paths dependent on their priority. Further, a scheduling mechanism drops packets according to their effect on the overall video distortion. This work, however, does not take into account the end-to-end link quality estimation and node-disjoint multiple paths.

[Lin et al. 2010] developed the Adaptive Reliable Routing Based on a Cluster Hierarchy for Wireless Multimedia Sensor Networks (ARCH) to balance energy consumption and meet required reliability, adjusting the transmission power, together with an energy prediction mechanism. In [Lin et al. 2011], Energy Efficiency QoS Assurance Routing in Wireless Multimedia Sensor Networks (EEQAR) employs a social network analysis to optimize network performance. Nevertheless, both proposals implement multi-hop communication inside a cluster, adding extra overhead for route discovery. Further, they do not consider link quality as metric for route selection, neither the usage of multiple paths. These solutions also lack of QoE-based evaluation.

[Lari and Akbari 2010] introduced a node-disjoint multiple routing, and consider free buffer size, residual energy, hop-count, and packet loss rate to score and classify paths. Paths with better conditions achieve higher scores and are used to transmit higher priority video packets. On the other hand, [Jayashree et al. 2012] propose to analyze the image to find some common regions (overlapping) and some not common regions (non-overlapping). The path with the highest score has the best condition for sending packets with overlapped area. However, these two works consider a flat architecture, which reduces network lifetime [Ehsan and Hamdaoui 2011], and the route selection does not take into account end-to-end link quality, which leads to unreliability. The proposal of [Jayashree et al. 2012] carries out image processing, which consumes time and energy.

From the related work analysis, we conclude that node-disjoint multiple path routing protocols for WMSNs, together with a route selection scheme that considers both cross-layer information and end-to-end link quality estimation with a minimal signaling overhead increases reliability. Moreover, a video-aware mechanism to protect priority frames in congestion/link error periods enhances the video quality from the human's experience. However, existing routing protocols for WMSNs do not take into account all of these relevant characteristics into a single hierarchical routing proposal to support QoE-aware multimedia transmission, while achieving energy-efficiency.

3. The Video-aware MMtransmission Routing Protocol

This section presents a video-aware multiple path hierarchical routing protocol for efficient multimedia transmission over WMSN, called video-aware MMtransmission. The protocol finds node-disjoint multiple paths and evaluates paths by introducing an end-to-end link quality estimation, which includes a minimal signaling overhead. The proposed protocol takes into account the frame relevance to provide load balance, and increase the video quality from user's perspective.

3.1. WMSN Scenario

We assume a WMSNs composed of heterogeneous nodes, categorized into sensor and camera nodes, as illustrated in Figure 1. The sensor nodes (SN_i, i = 1, 2, ..., n) are restricted in terms of energy supply, processing and memory space, while camera nodes (CN_j, J = 1, 2, ..., m) are equipped with an alternative energy source, complementary metal-oxide-semiconductor (CMOS) camera, and very low bit rate image encoder. In this paper, we denoted multiple SN_i or CN_j, as $SN_{i(s)}$ or $CN_{j(s)}$ respectively.

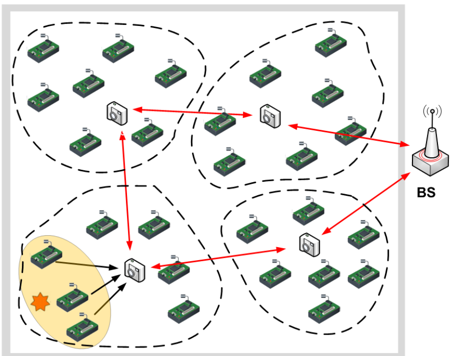


Figure 1. Network architecture

To support its operation, video-aware MMtransmission demands that $CN_{j(s)}$ act as Cluster-Heads (CHs), and $SN_{i(s)}$ act as non-CHs. $CN_{j(s)}$ carry out more complex tasks, such as time-slot allocation, synchronizing non-CH transmissions, data aggregation, real-time video retrieval, and routing packets. On the other hand, $SN_{i(s)}$ perform simple tasks, such as periodically sending physical scalar measurements to a CN_j. In this way, $CN_{j(s)}$ can predict event occurrence, such as flooding, fire, intruders and others, by using existing models or methods and physical scalar measurements. As soon as $CN_{j(s)}$ detect an event, they should start the multimedia retrieval and transmission to provide users more precise information than simple scalar data.

3.2. Operation Model of Video-aware MMtransmission

Video-aware MMtransmission relies on hierarchical network architecture with heterogeneous nodes to reduce the overall communication overhead, maximize the network lifetime, and improve scalability. The operation of MMtransmission has as basis the Multi-hop hierarchical routing protocol for Efficient VIdeo communication over WMSN (MEVI), proposed in [Rosário et al. 2012], since MEVI's properties enable multi-hop communication taking into account scalability and energy-efficiency.

The data transmission consists of intra-cluster and inter-cluster communications. For intra-cluster communication, nodes create clusters with low signaling overhead, where non-CHs send sensed values in a specific time-slot to their CH. Further, each CH receives the data packets, aggregates them into a single packet and assigns the time-slots according to the TDMA (Time Division Multiple Access) schedule.

On the other hand, during the inter-cluster communication, there is a multi-hop communication between CHs and Base Station (BS) to enable the CHs forwarding the aggregated and multimedia data packets to the BS, and the BS can also request multimedia content to a CH if necessary. Thus, MEVI contains a route discovery period by exploiting a reactive scheme to find routes on demand to decrease the overhead and improve the scalability of the system. The route discovery process involves the CHs broadcasting route request (RREQ) and reply (RREP) messages. In this way, each received RREP means an available route to the destination node.

These messages search available routes and assist the route selection process by collecting information of *Remaining Energy (RE_t)* and *Hop Count (HC)*. Hence, each path has associated a Link Quality (LQ) value, which is applied to score and classify the links. The LQ value is computed according to Eq. 1 by considering *RE_t*, and *LQI (Link quality Indicator)* for the next hop, *HC*, and weights to give a degree of relevance to each metric.

$$LQ = \alpha \times \frac{RE_t}{E_0} + \beta \times \frac{LQI}{LQI_{max}} + \gamma \times \frac{HC_{max} - HC}{HC_{max}} \tag{1}$$

LQ returns values from 0 to 1, the sum of weights (α, β, γ) is equal to 1, E_0 represents the initial energy, LQI_{max} represents the maximum value for LQI, and the maximum Hop Count (HC_{max}) depends on the network diameter.

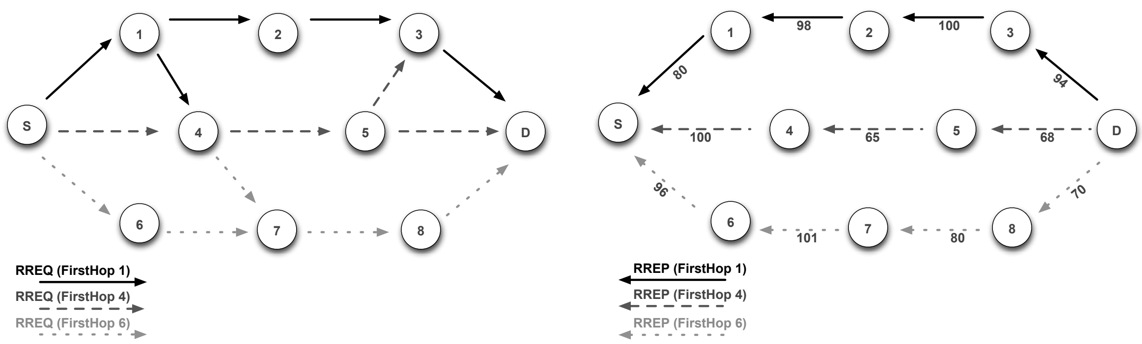
3.3. Node-disjoint Multiple Route Discovery

The video-aware MMtransmission protocol finds multiple paths between CHs and BS by transmitting RREQ and RREP messages, as shown in Figures 2(a) and 2(b). The proposed protocol gives a number for each possible path by including the first-hop into the RREQ message, which is the first node to broadcast RREQ, after the source node (S) initiates route discovery. Figure 2(a) illustrates this operation, where the S broadcasts a RREQ message to find possible multiple paths to the destination node (D). The RREQ message traverses by three possible paths with different first-hop, i.e. 1, 4 and 6. Additionally, a node never rebroadcasts duplicated RREQs or with different first-hop compared to prior received RREQs. For example, node 7 received RREQs with first-hop 4 and 6, and then it knows that those paths are not node-disjoint. In this case, node 7 does not rebroadcast and adds both paths into the routing table.

As soon as the RREQ messages reach the destination node, it creates new path entries to the source node for each incoming request, even when RREQs have a different first-hop. The destination node transmits a corresponding RREP message for every incoming RREQ message, with the aim to establishing a full bidirectional multiple path, as shown Figure 2(b). The RREP message travels back to reach the source node, which creates new path entries for every incoming RREP.

Existing works classify the paths according to hop-count or single-hop metrics. In contrast to that, the video-aware MMtransmission protocol evaluates the end-to-end link quality communication by using regions of connectivity presented by

[Baccour et al. 2011]. Such work classifies the links by means of the PRR (Packet Reception Ratio) value into three regions of connectivity, namely connected (PRR higher than 90%), transitional (PRR between 10% and 90%), and disconnected (PRR lower than 10%). Based on these information, video-aware MMtransmission must find routes composed of links with higher PRR to support multimedia transmission with higher transmission reliability. Moreover, the proposed protocol supports multimedia dissemination with higher quality level, by using information about the frame importance from the user's point-of-view to protect key frames of congestion/link error periods, as explained latter.



(a) Route request (b) Route reply

Figure 2. Video-aware MMtransmission route discovery

In specific terms, to estimate the end-to-end link quality, we count the number of disconnected and connected links by including two counters into RREQ and RREP messages. We define the bounds of disconnected and connected regions by means of two LQI thresholds, i.e. LQI_{bad} and LQI_{good}, which should be defined according to experiments, as shown Figure 3. LQI lower than LQI_{bad} implies a disconnected link, and with LQI higher than LQI_{good} provides a connected link. Thus, as soon as a node receives a RREQ/RREP, it derives the LQI value to classify the links into disconnected and connected, and then updates the counters of RREQ/RREP messages.

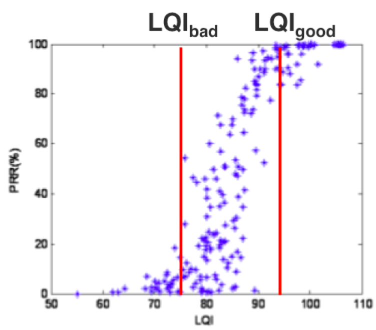


Figure 3. Regions of connectivity

We introduce **Path Quality (PQ)** to score the paths based on cross-layer and end-to-end link quality information. PQ is computed according to Eq. 2 by considering single hop metrics (RE_t and *LQI*), and end-to-end metrics (number of *Disconnected Links (DL)* and *Connected Links (CL)*). Moreover, PQ includes weights to give priorities for each metric, which are defined based on the scenario characteristics and application requirements. As result, video-aware MMtransmission selects routes with high PQ to provide reliability for data delivery and increase the system performance.

$$PQ = \alpha \times \frac{CL}{HC} + \beta \times \frac{HC - DL}{HC} + \gamma \times \frac{RE_t}{E_0} + \sigma \times \frac{LQI}{LQI_{max}} \tag{2}$$

PQ gives values from 0 to 1 for each possible path, and the sum of weights $(\alpha, \beta, \gamma, \sigma)$ is equal to 1.

Figure 2(b) exemplifies the evaluation of the paths based on end-to-end information by assuming LQI_{bad} = 75 and LQI_{good} = 95, as defined in accordance with Figure 3. Table 1 shows the LQ (Eq. 1) and PQ (Eq. 2) values for each possible path between S and D. Considering the lowest number of hops, we select the route 2. However, this route is composed of two bad links, which will cause higher packet loss. Taking into account LQ, we select route 2 as the best and route 3 as alternative. However, these routes contain two bad links that also cause higher packet loss. Considering PQ, we select the route 1 as the best route, which is composed of more reliable links, and thus able to deliver video content with higher quality level.

Table 1. Routing table example

Route	Possible Paths	PQ	LQ
1	S-1-2-3-D	0.74	0.36
2	S-4-5-D	0.63	0.58
3	S-6-7-8-D	0.73	0.44

It is important to highlight that [Baccour et al. 2011] define connected links by means of PRR values higher than 90%. However, we decreased the threshold to 80%, because in certain cases it is difficult to find a higher number of links belonging to the connected region. Moreover, PRR higher than 80% still provides multimedia transmission with good quality from a user's experience. Additionally, we increase the threshold for disconnected region from 10 to 20%, because links with PRR lower than 20% deliver videos with very bad quality from a user's perspective.

3.4. Video-aware Multimedia Transmission

Three types of frames compose a compressed video. Intra frames (I-frames) provide a reference point for decoding a received video stream, i.e., reference for all the other frames. Predictive-coded frames (P-frames) give an increased level of compression compared to I-frames. Bi-directionally predictive-coded (B-frames) use the previous and next I-frames or P-frames as their reference points for motion compensation [Greengrass et al. 2009]. The frame sequence that depends on an I-frame composes a Group of Pictures (GoP). For example, a GoP length of 10 frames means that the GoP starts with an I-frame followed by a sequence of 9 P or B frames.

The frame loss has different influence on the user's perception, and causes distortion and error propagation. In this way, the loss of an I-frame affects the other B- or

P-frames of the same GoP by propagating the error within the whole GoP. For loss of P-frames, the error propagates by the remaining P- and B-frames within the GoP. Additionally, the loss of P-frames at the beginning of a GoP causes more video distortion than P-frames at the end of a GoP. Finally, for loss of B-frames, the error does not propagate, since B-frames are not used as a reference for other frames.

To support QoE-aware multimedia transmission and load balance, the proposed protocol protects priority frames of congestion/link error periods by selecting reliable paths to send the video packets based on frame importance. The path with highest PQ is more reliable for transmitting priority frames (I-frame and the firsts P-frames), and thus, ensures a minimum packet loss. On the other hand, less priority frames (B-frames and the last P-frames) are transmitted via less reliable paths (alternative paths).

However, there are cases that the alternative paths provide a low reliability, because it suffers a higher packet loss rate. Then, as soon as the video-aware MMtransmission protocol detects an alternative route with a PQ lower than a minimal PQ (PQ$_{min}$), the protocol transmits the video packets, by using single path communication. To define PQ$_{min}$, we performed experiments and present the results in the next section.

4. Performance Evaluation

This section describes the simulations conducted to evaluate the video-aware MMtransmission protocol, and also shows the impacts and benefits of our protocol for multimedia distribution over WMSNs. First, we present the methodology used to evaluate video-aware MMtransmission. Then, we present and analyze the simulation results.

4.1. Simulation Parameters and Evaluation Metrics

We evaluated the performance of video-aware MMtransmission routing protocol by means of simulations. For that, we used the Mobile MultiMedia Wireless Sensor Network (M3WSN) OMNeT++ framework [Rosario et al. 2013]. This is because M3WSN framework includes a model to generate sensor data, which corresponds to a real process with spatial data correlation and also variability over time. This data was used to predict event occurrence, such as flooding, fire, intruders and others. Hence, as soon as $CN_{j(s)}$ detect an event, they should start the multimedia retrieval and transmission. In our simulations, we considered the features and energy consumption of $SN_{i(s)}$ equipped with a CC2420 radio, and $CN_{j(s)}$ equipped with CC2420 radio and CMOS camera (CMUcam).

We conducted simulations with different solutions of multi-path routing under MEVI to compare the results with video-aware MMtransmission. These solutions use similar approaches compared to existing routing protocols. The first solution classifies the routes according to the number of hops (*MMEVI-HC*), which is similar to Ad hoc On-demand Multipath Distance Vector (AOMDV), and [Hurni and Braun 2008] for route selection. The second solution, called *MMEVI-LQ*, evaluates the routes according to a single-hop metric, i.e., LQ (Eq. 1), which is the metric used by MEVI. Additionally, LQ uses metrics similar to [Lari and Akbari 2010] and [Jayashree et al. 2012] (see Section 2). For the last solution, called *MMEVI-PQ*, the paths are evaluated based on end-to-end link quality estimation, i.e., PQ (Eq. 2). This solution is used to evaluate the mechanism of video-aware MMtransmission to exclude alternative paths with PQ lower than PQ$_{min}$. Simulations were carried out and repeated 20 times to provide a confidence interval of 95% (vertical bars in graphics). Table 2 summarizes the basic simulation parameters.

Table 2. Simulation parameters

Parameter	Value
Field size	80x80
Base station location	40, 0
Total number of Nodes	100
Number of CHs	36
CHs topology	Grid
Non-CHs topology	Uniform
Initial Energy for non-CHs	14 J
Transmission Power	-10 dbm
Path loss model	Lognormal shadowing model
Video sequence	Container
Video Encoding	H.264
Video Format	QCIF (176 x 144)
Frame Rate	26 fps

It is important to highlight that $SN_{i(s)}$ are used to periodically send packets to a CN_j. Thus, different $SN_{i(s)}$ density does not reduce the video quality. Regarding to overhead of video-aware MMtransmission, our protocol adds low byte overhead to include the additional fields in RREQ/RREP messages compared to existing solutions. On the other hand, the packet overhead depends on the number of alternative paths.

Existing works classify the videos according to their motion into three categories, namely *low, median and high*. For example, [Aguiar et al. 2012] classify the Container video sequence (taken from Video Trace Library [Library 2012]) with low movement, which means that there is a small moving region of interest on a static background, i.e., a ship crossing a lake. This characteristic is required for many WMSN/IoT applications, such as environmental monitoring and smart parking. Thus, these factors explain our option for transmitting the Container video sequence.

Traditionally, routing protocols are evaluated from a network/packet level point-of-view by using QoS metrics, e.g., delay, jitter, or loss. However, QoS metrics do not reflect user's perception and, thus, fail in capturing subjective aspects associated with human's experience. In this context, QoE metrics/approaches overcome the limitations of current QoS schemes regarding human's perception and subjective aspects. Therefore, to highlight the protocol reliability from the user's point-of-view, we evaluate the video-aware MMtransmission by using two well-known objective QoE metrics: Structural Similarity (SSIM) and Video Quality Metric (VQM).

SSIM measures the structural distortion of the video to obtain a better correlation with the user's subjective impression. SSIM has values ranging from 0 to 1, and higher value means better video quality. On the other hand, VQM measures the "perception damage" of video experienced, based on features of the human visual system, including distinct metric factors such as blurring, noise, color distortion and distortion blocks. For VQM, a value closer to 0 means a video with a better quality.

We measure the energy-efficiency of our protocol by devising an ad hoc metric called of Energy-Quality Index (EQI). EQI represents the trade-off between the video quality achieved (i.e., by means of SSIM) to the burden energy (E) at the intermediate nodes along a path, and is computed according to Eq. 3. The values of SSIM and E are normalized with number of hops [Boluk et al. 2011].

$$EQI = \frac{\Delta SSIM}{\Delta E} \tag{3}$$

4.2. Simulation Results

This section presents the experiments to find PQ$_{min}$, which impacts on the performance of video-aware MMtransmission. We conducted simulations to measure the video quality level and energy-efficiency. PQ$_{min}$ is used to avoid packet loss on unreliable paths, and thus, ensures multimedia transmission with a minimal video quality level. Alternative paths with PQ lower than PQ$_{min}$ are not used. Based on the results shown in Figure 4, a video transmitted through a path with PQ below 0.4 obtains poor video quality level from the user's perspective, and for this reason we selected PQ$_{min}$ = 0.4.

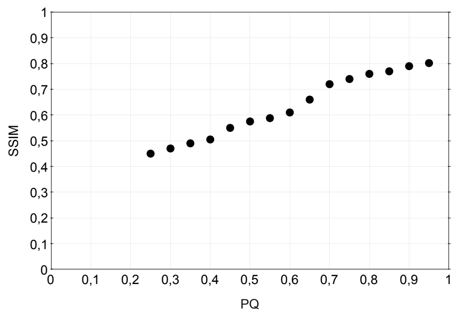


Figure 4. SSIM according to path quality value

We measure the average of SSIM and VQM for all transmitted videos with respect to the length of route (number of hops), as shown in Figures 5 and 6. By analyzing Figure 5, we see a higher and similar video quality for a route up to 2 hops, regardless of protocols. This happens due to the source node is closer to BS, which decreases interference and packet drops at intermediate nodes. Nevertheless, in the best case video-aware MMtransmission improves the SSIM by 5% compared to the other solutions, and in the worst case the protocols have the same performance.

On the other hand, a path can experience links with bad communication quality when the routing protocol does not estimate the end-to-end link quality for routes with more than 3 hops. For example, MMEVI-HC selects routes based on the number of hops, which makes it unreliable. This can be explained by the fact that short routes in terms of hops are more susceptible to packet loss due to both noise and interference. By evaluating single-hop links, MMEVI-LQ increases the video quality compared to MMEVI-HC. However, this is still lower than solutions that evaluate the end-to-end link quality. Our protocol provides a gain in around 12% for SSIM metric compared to MMEVI-HC and MMEVI-LQ, for routes with more than 3 hops. This is because our protocol evaluates the end-to-end link quality communication with a minimal signaling overhead to increase the packet delivery ratio. Moreover, video-aware MMtransmission provides higher reliability than MMEVI-PQ, because when the alternative routes are not reliable enough, the proposed protocol uses the single-path communication.

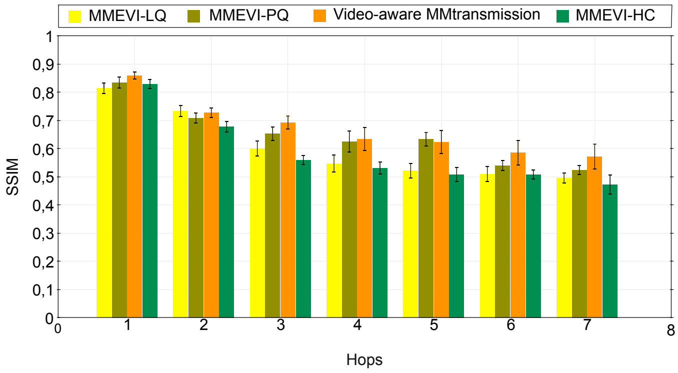


Figure 5. SSIM with respect to number of hops

Figure 6 shows the video quality by using the VQM metric. It is important to highlight that low VQM values means higher video quality. By analyzing VQM results, we find similar observations compared to SSIM results. By transmitting video packets via video-aware MMtransmission, the VQM improves by around 10%, and in the worst case our protocol has a similar video quality as the other solutions for routes up to 2 hops. On the other hand, for routes with more than 3 hops, the video-aware MMtransmission routing increases the VQM by 40%, 30% and 10% compared to MMEVI-HC, MMEVI-LQ and MMEVI-PQ, respectively. Thus, based on SSIM and VQM results, we confirm the benefits of video-aware MMtransmission to assure higher video quality from user's perception for disseminating video flows.

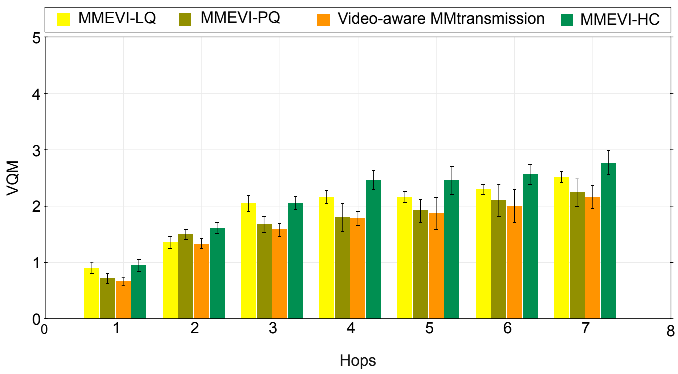


Figure 6. VQM with respect to number of hops

Figure 7 illustrates the energy costs to provide a certain video quality level. Upon analyzing the results, we can see that video-aware MMtransmission increases the EQI by around 10%, which means that the proposed protocol provides the best trade-off between the video quality per unit of spent energy. This is because our protocol evaluates the end-to-end link quality communication, which improves the packet delivery. Additionally, it avoids alternative paths with low reliability by considering a minimal PQ value.

To show the benefits of transmitting video streams using video-aware MMtransmission from the standpoint of the end-user, a random frame was selected (frame 257) from the transmitted video, as displayed in Figure 8. Frame 257 is the moment when two birds fly across the scene. For some applications, the moment/frame with a moving region of interest, e.g., intruder/event and, in this case a bird, crossing a static background

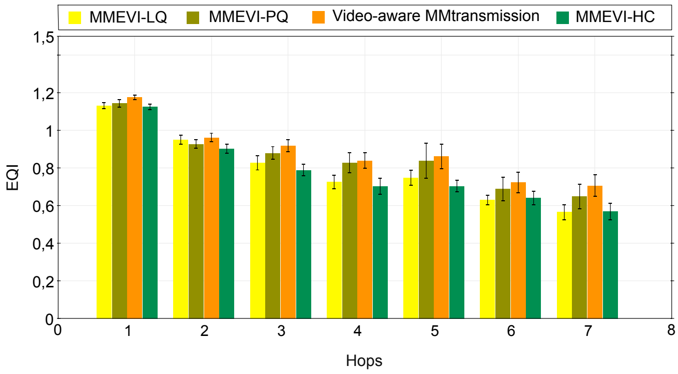
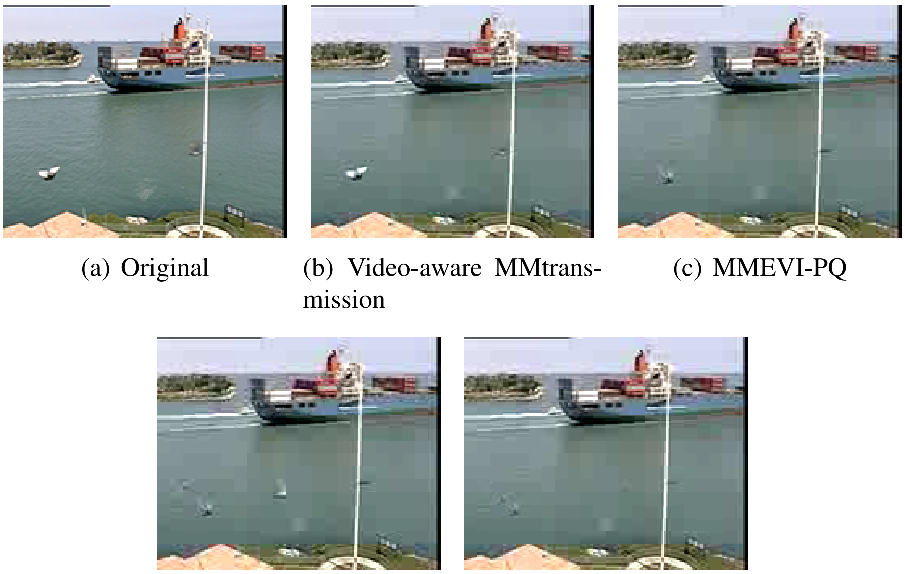


Figure 7. EQI with respect to number of hops

is useful to detect an intruder or to analyze the impact of an event. Thus, the video stream provides more precise information, gives support to end-users (or systems) to visually verify the real impact of event, and be aware of what is happening in the environment based on visual information.



(a) Original

(b) Video-aware MMtransmission

(c) MMEVI-PQ

(d) MMEVI-HC

(e) MMEVI-LQ

Figure 8. Frame 257 of container video sequence

The benefits of video-aware MMtransmission are evident by comparing its received frame (Figure 8(b)) with the other solutions (Figures 8(d), 8(e) and 8(c)) and also with the original frame (Figure 8(a)). For example, the transmitted frames by using MMEVI-HC, MMEVI-LQ and MMEVI-PQ have a higher distortion in the ship and on the lake compared to the original frame (see Figure 8(a)) compared to the frame transmitted via our protocol (see Figure 8(b)). Moreover, the bird does not appear in the same position because this frame was lost, and thus it was reconstructed based of the previously received frames. In contrast to that, the frame transmitted via video-aware MMtransmission presents only few distortions, and the bird appears in the same position. This is because our protocol proposes a mechanism to protect priority frames in congestion/link error periods by transmitting via reliable paths, and thus, enhances the video quality level from the human's experience. Additionally, video-aware MMtransmission evaluates the routes in an end-to-end fashion by a cross-layer approach with a minimum overhead.

5. Conclusion

This paper introduced the video-aware MMtransmission routing protocol to provide load balance and QoE-aware multimedia transmission, while achieving energy-efficiency. In specific terms, it searches for node-disjoint multiple paths, evaluates the paths according to cross-layer information and end-to-end link quality estimation. Thus, it gets to select the most reliable route to send priority frames (i.e., based on user's perspective), and alternative routes to distribute lower priority frames.

Simulations were carried out to show the benefits of video-aware MMtransmission for multimedia dissemination. Analyzing the simulation results, it was found that video-aware MMtransmission enables video distribution with a minimal quality level from a user's perspective. This was found by evaluating the proposed protocol through well-known objective metrics (SSIM and VQM) as well as showing video frames. Transmitting video packets via video-aware MMtransmission, the SSIM has a gain of 10% and the VQM improves by 10% and 40% compared to other solutions. Thus, we can conclude that the proposed video-aware MMtransmission protocol delivers video with QoE assurance, while also achieving energy-efficiency.

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